

Editorial

Geotechnical engineers tend to make complicated designs, caused by the increasing complexity of our infrastructure and of underground building. This tendency puts a high demand on the capability of the prediction of deformations.

Before designs are realised in practice, their reliability has to be tested. Today's computers and software allow for solutions in finite elements. The FEM has been used in structural engineering for over 20 years. Geotechnical engineering, however, is far more complex. Consider the diverse material behaviour of rock, clay and sand, the different kinds of structures we tend to use for reinforcement of soil, etc.

From the start, Plaxis has been developed for the practical engineer, who is always pushed to find reliable results in a limited time-span. This calls for software that is robust and comprehensive to use. Needless to say, the software must be capable of modelling the behaviour of soil, structures and the interaction between soil and structures. These ideas have been realised in the Plaxis program. The Plaxis formula has found it's adoption to engineers world wide.

Some 5 years ago, the Plaxis Users Association (NL) was founded. Their objective is to promote the exchange of experiences by users and to publish a bulletin to inform users on new developments, to provide more background, and inform users on planned activities. In the past few years the group of Plaxis users has expan-

ded rapidly. Now 75% of all Plaxis users are located outside the Netherlands. Last year, Plaxis bv and the Users Association agreed to join forces in publishing an international users bulletin, for the benefit of all users.

The first international edition has found your desk. In the Plaxis bulletin, you will find regular reports on new and current developments in the program. The column by Vermeer, a good tradition, will be continued. In his column, Vermeer gives theoretical backgrounds on geotechnical phenomena. In 'Plaxis Practice' contributions by users are printed. A new item in the bulletin is the Users Forum. In this column, letters to the editor and interesting letters or questions to the Plaxis help desk can be printed. You will find useful tips here ! Finally the agenda will show planned activities, such as: users meetings, courses, conferences, etc.

We hope you will enjoy reading the Plaxis bulletin. Needless to say, we are looking forward to your contributions in the Plaxis bulletin. After all it is a service from users to users !

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Recently I was asked to perform some finite element calculations to check the design of a lining within a shield tunneling project. Conventional spring-model computations had already been carried out and I was requested to check resulting bending moments by means of non-linear FE-analyses.

The available input data for the cohesionless soil layers was more or less classical, with oedometer moduli for the soil stiffness and friction angles being given for the soil strength. Obviously such data suits the Mohr-Coulomb soil model and one wanted me to use this elastoplastic model. As I was more in favor of the new Hard-Soil model, we decided to perform some trial calculations using both models. In order to get optimal insight into the different performance of both models, we considered a simple homogeneous subsoil of medium dense sand as indicated in Table 1.

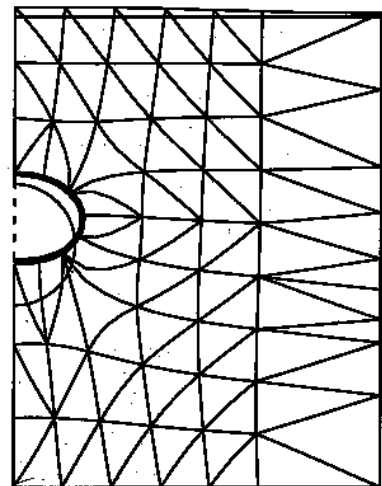
Table 1 material properties.

Young's modulus, E	MPa	24 MPa
Poisson's ratio, ν	----	0.33
Friction angle, ϕ	°	35
Dilation angle, ψ	°	5

The Young's modulus is reasonable for the considered stress level around the tunnel ($\sigma_{vo}^i \approx 150 \text{ kPa}$, $\sigma_{ho}^i \approx 75 \text{ kPa}$), but it should be realised that it is a first-loading modulus and not an unloading-reloading modulus. Following Duddeck (1985), however, whom I consider the "godfather" of tunnel mechanics, one would need the high unloading-reloading modulus rather than the above relatively low firstloading stiffness modulus. For this reason, I wanted to use the Hard-Soil model, as here we do not need to make a selection a priori. Indeed, this new model selects automatically between the various types of loading; not on a structural level, but on a soil element level. Hence the new model will automatically allow for a stiff bedding underneath, a soft bedding

on top and an intermediate stiffness on the sides of the tunnel.

Figure 1 shows the deformed mesh as obtained by using the Mohr-Coulomb with a fixed (first-loading) Young's modulus. In order to gain an understanding of the considerable uplift of the tunnel, it should be realised that we are considering a fairly shallow tunnel with a diameter of 8m and an axis only 15m below ground surface. Considering a high groundwater table the tunnel is fully submerged, and surrounding pore pressures provide an uplift force of about 500 kN per meter of tunnel length. To understand the deformations it should also be pointed out that we modelled the excavation simply by switching off soil elements and eliminating the waterpressures inside the tunnel. Ground loss due to excavation in excess of the tunnel area might have been modelled, but we did not do so. Similarly, we might have modelled a lining with hinging tubing, as it usually is in shield tunneling, but we assumed a stiff continuous lining for the sake of simplicity.

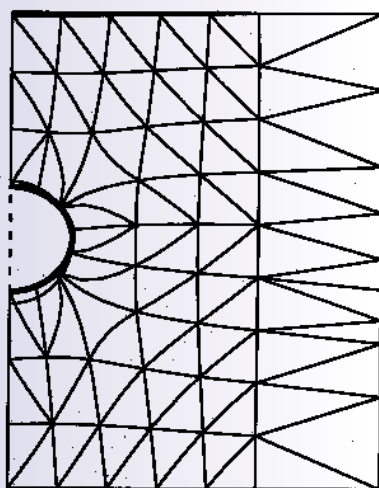


Extreme displacement 34 mm

Figure 1 Deformed mesh by MC-model.

Figure 2 shows the deformed mesh as computed by using the Hard-Soil model and $E_{unloading}$ five times larger than $E_{first\ loading}$. Obviously this stress-strain model accounts for more effects of soil behaviour that just the difference between first loading and unloading and unloading/reloading, but those do not

matter so much for shield-tunneling problems as considered here. In fact, the HS-model results of Figure 2 can also (approximately) be obtained by means of a MC-model analysis with an unloading/reloading modulus of $E=120$ MPa. In this way one will also obtain a small surface settlement trough, together with some deflection of the tunnel roof and some 1 cm upheave of the tunnel floor, similar to Figure 2. Hence Duddeck is right: Shield-tunneling problems are governed by the unloading reloading stiffness, rather than the first-loading modulus of surrounding soil.



Extreme displacement 9 mm

Figure 2 Deformed mesh HS-model.

Now it might be concluded that we do not really need the Hard-Soil model, as the Mohr-Coulomb model can also do the job, at least in combination with a suitable choice of the soil stiffness modulus. Indeed, this may often hold true, but in many cases one does not know whether the problem is governed by the first-loading modulus, the unloading modulus or a value in between. More over some aspects of the problem cannot properly be assessed on the basis of a single-parameter analysis, e.g. the shape of the surface settlement through tends to be badly predicted using the simple MC-model. In addition one often has to deal with different stages of loading and unloading, which demand different stiffnesses. Realistic tunnel analyses require for instance mostly the consideration of surface loads. For such stages of loading, it is obviously incorrect to use

an unloading modulus. The chief advantage of the HS-model over the MC-model is the automated determination between the two soil stiffnesses for all different stages of loading and unloading. In tunneling problems this is extremely important as the soil stiffnesses also has a significant effect on bending moments in the tunnel lining.

P.A. Vermeer, Stuttgart University

PLAXIS Practice

CONSTRUCTION OF THE IRD BASEMENT IN SINGAPORE

This contribution describes the construction of the IRD Basement in Singapore. The construction had particular constraints because it is adjacent to an existing Mass Rapid Transit (MRT) Tunnel. The basement is four stories, 16m deep, with a five story podium and with a high rise office block on top of that.

The geology of the site is complex being located on the edge of a buried valley infilled with marine clay. Hence part of the site is located on these marine clays, whereas the rest of the site is situated on alluvium and residual soils. Underlying these soils are the older sediments termed the Old Alluvium, and below that there are decomposed and weathered granite forming the bedrock.

The project was a design and build contract, with particular requirements to protect the MRT Tunnel as the tunnel was floating in the marine clay. One of these requirements was that the Tunnel-Basement interaction be studied by finite element analysis. This was asked for to demonstrate that the movements on the tunnel would be less than 15mm total in any plane, and 10mm over any 6m length.

The initial analysis was performed by a 1-d program based on a Winkler spring approach. In order to maintain force consistency, the strut forces from the 1-d model were imposed on

the Plaxis model version 4.0. This gave maximum wall deflections on the order of 65mm, with movements at the tunnel of around 12mm.

During construction, maximum wall movements were typically around 20mm by basement three excavation level, with the tunnel moving up to 6mm. This was not consistent with the predictions of the initial model. An additional analysis was required to verify that the system would still perform satisfactorily.

This was initially performed in the Plaxis professional version 4.1. This model was calibrated using the basement one movements, then verified using the basement two and three movements. The movements on basement four were then predicted using the calibrated model. At this stage the model was not calibrated for pore pressures.

The results gave a good prediction for horizontal movements of the tunnel, but were not so good for vertical movements. This was ascribed to the pore pressure not being correctly calibrated (though of the right general behaviour). Manual adjustment of the vertical settlement for pore pressure corrected the vertical movements to within survey tolerance.

The analysis was re-done for Plaxis version 6.1 in order to use the increased modelling capabilities of the latter version (a.o. elastoplastic consolidation).

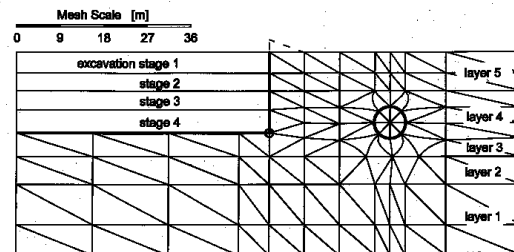


Figure 1 Finite element mesh.

Figure 1 shows the version 6 mesh, the material properties are listed in Table 1. As a first estimation, these properties were kept as identical as possible between the two versions, though some small changes were needed as a result of the different capabilities of the two programs. In particular the Poisson's ratio has been altered, to account for the pore pressure changes during construction. The only major alteration between the two analyses was the inclusion of a three month consolidation period. This shows that there was no significant consolidation during the construction

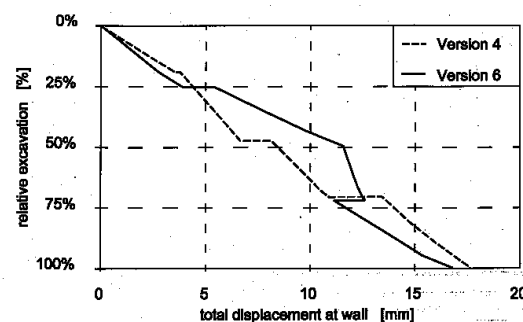


Figure 2 Total displacements at wall.

Table 1 Material properties.

	units	Layer 1	Layer 2	Layer 3	Layer 4	Layer 5
Material Model	----	MC	MC	MC	MC	MC
Material behaviour	----	Undrained	Undrained	Undrained	Undrained	Undrained
Dry weight, γ_d	kN/m ³	19	18.5	16.5	16.5	15
Wet weight, γ_w	kN/m ³	19	18.5	16.5	16.5	18
Permeability x, k_x	m/s	1.0E-8	1.0E-8	1.0E-9	1.0E-9	1.0E-7
Permeability y, k_y	m/s	1.0E-8	1.0E-8	1.0E-9	1.0E-9	1.0E-7
Poisson's ratio, ν	----	0.25	0.30	0.25	0.25	0.35
Shear modulus, G	kN/m ²	4.0E5	1.0E5	25000	20000	10000
Cohesion, C	kN/m ³	20	5	15	10	10
Internal friction angle, ϕ	°	34	30	22	22	28
Angle of dilatancy, ψ	°	4	0	0	0	0

period, and that the currently used permeabilities are too high. Future analysis will correct this.

Figure 2 shows the wall movements for V4 and V6. Figure 3 shows the tunnel movements. The version 6 analysis is a little under the wall movements, as a result of the consolidation. Both programs give good results as a predic-

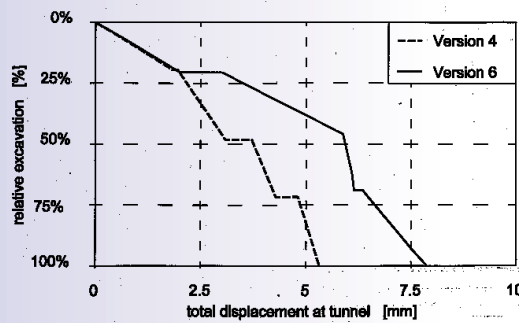


Figure 3 Total displacements at tunnel.

tor of the likely movements. It should be noted, however, that the V6 calculation was just a first approach using most of the parameters as calibrated for V4 but following a different calculation procedure. A further improvement could be obtained by calibrating the parameters for the V6 calculation procedure. Particular when using the Mohr-Coulomb model, it is essential to choose stiffness parameters in relation with the leading stress path.

Sergei Terzaghi,
Woodward-Clyde (NZ)

New developments

The Plaxis Research and Development team is continuously working on maintenance, improvements and extensions of the program, which results in a new version approximately every two years.

Developments can be divided into two groups:

1. Scientific and technical implementations
2. Functional improvements and extensions

Subjects belonging to the first group are developed in close relationship with European universities, institutes and specialists in the field of geotechnics and numerical methods. Current projects in this category are:

- 3D modelling. This project is executed in cooperation with the University of Delft, The Netherlands. Apart from a simplified 3D calculation method for tunnels, a full 3D module is under development for the analysis of laterally loaded piles and circular foundations. In a new research project the module will be extended to account for a more flexible and efficient way of 3D modelling using parallel cross sections.
- Dynamic behaviour of soils and structures. The University of Grenoble in France is involved in the development of a dynamic module for the analysis of vibrations in soil structures. Special attention is paid to the time integration scheme and, in general, to the robustness of calculation procedures. A major issue of this project is the boundary treatment to avoid spurious reflections. Later in this project the dynamic behaviour of soil structure interaction will be treated in more detail.
- Creep behaviour of soft soils. A new creep model was developed at the University of Stuttgart, Germany. In this model non-reversible volume strains are assumed to be due to creep behaviour. The concept of pre-consolidation is used to determine the creep rate. Single point algorithms have proven that the model predicts realistic creep behaviour of soft soils. At this moment the model is being implemented in Plaxis, after which extensive testing will be done based on practical applications.
- Non-steady groundwater flow. Recently the groundwater flow module was extended with storativity terms and a time stepping procedure to account for the simulation of non-steady flow. At this moment the input procedures are extended to allow for varying boundary conditions. A full interaction with elastoplastic deformation analysis is scheduled for the end of this year.

Extensive testing procedures are executed after all these implementations in order to maintain the robustness and reliability of the program. Some of the scientific and technical implementations will be made available in the next version 7.

Subjects belonging to the second group of developments are primarily based on suggestions by users. The Plaxis team has the ability to translate these ideas into functional and efficient procedures. Current developments in this category are:


- Batch processing and logging
- Improved visualisation of stresses and stress paths
- Enhanced and fully automatic mesh generation
- Windows graphical user-interface

So far, the demand for technical Windows application programs was relatively low. Moreover, program development tools were hardly available or suffered from serious limitations. For that reason the Plaxis team has waited with developments in this direction. The previously described situation is now changing rapidly, particularly with the availability of new operating platforms and convenient development tools. As a result, the team has started to develop a completely new graphical user-interface. Particularly in a Windows environment it is a real art to make technical applications functional, efficient and user-friendly. On the other hand, it enables new possibilities for communication and data transfer between programs. In this respect there are plans for an integrated data base and expert system to support users interactively during the input of geometrical and material data.

In conclusion, there is a long list of current and future developments which will be executed to make Plaxis comply with the demands of tomorrow's world. At the same time it is the intention to maintain the 'easy entrance' enabling new users to join the group. In coming bulletins some of the current developments

will be discussed in greater detail.

Ronald Brinkgreve, Plaxis bv



A short course, 'Computational Geotechnics' was given at the University of Colorado at Boulder on July 22-24, 1996. The course was organized within the Department of Civil, Environmental, and Architectural Engineering by Professor Stein Sture and Professor Emeritus Robert L. Schiffman.

The course was attended by 38 persons representing a cross-section of geotechnical engineers in industry, government and universities. In particular university faculty members from Chalmers University (Gothenburg, Sweden), Cornell University, the Georgia Institute of Technology (Georgia Tech), the University of California, the University of Texas at Austin, University of Akron (Ohio), and Colorado School of Mines participated.

The lecturers who discussed various aspects of Plaxis included Ronald Brinkgreve (Plaxis bv), Richard Davidson and Imran Gillani (Woodward-Clyde Consultants, Denver), W. Allen Marr (GEO-COMP Corporation), Sergei Terzaghi (Woodward-Clyde Consultants, New Zealand), Pieter Vermeer (University of Stuttgart, Germany), Arnold Verruijt (Delft University of Technology, The Netherlands), along with the course organizers.

The topics covered an introduction to the finite element method, the use of Plaxis to solve groundwater, consolidation, slope stability and bearing capacity problems.

Review of basic theory of elasticity and plasticity were also covered together with exercises based on these topics. Three out of twelve sessions were devoted to case history discussions involving deep excavations, coupled deformation and groundwater flow in the design of a deep basement wall. Numerous cases included work performed in Singapore, Shanghai, Fiji and Auckland, New Zealand.

It was announced that the USA agent for Plaxis will be Dr. W. Allen Marr (the GEOCOMP Corporation).

Stein Sture, Colorado University



It is the intention to publish incoming letters in this column, or questions that arrive at the Plaxis support desk that may be of benefit to other users. When appropriate, the incoming letters, or questions will be commented.

Question:

Can I choose my own scaling factor, instead of the default value that Plaxis uses in scaled plots of displacements and stresses.

Answer:

Yes, from Version 6 in all scaled plots the key combination <Alt><U> can be activated. This will allow the user to enter a relative scale factor. See also Reference Manual (Version 6), page 3-4.

Question:

Is there a possibility to get plots without text.

Answer:

Yes, from Version 5 in all plots the key combination <Alt><N> can be activated. This will omit the text from being printed (to screen, or to output device).

Question:

Is it possible to calculate more than two different groundwater situations ? Plaxis only seems to allow for 2 situations, i.e. Initial and Ultimate phreatic situation.

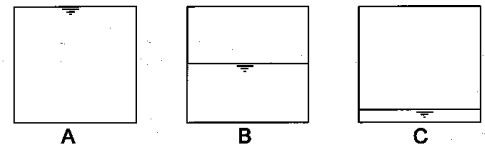
Answer:

Plaxis has a straight forward procedure for the input of 2 different groundwater situations, the Initial and Ultimate pore pressures. However, it is possible to model an unlimited number of different phreatic situations, when following the procedure which is described below.

As an example we consider the situation as indicated in figure 1. Before going into detail the meaning of some expressions should be clear.

INPUT LOAD: Input situations of loads are not active after input.

Initial pore pressures: Input situation, in



*Figure 1
Three different groundwater situations.*

which pore pressures are generated either from the input of the initial phreatic line, or resulting from an initial groundwater flow calculation.

Ultimate pore pressures: Second input option for pore pressures, called Ultimate pore pressures, basically similar to initial pore pressures.

ACTIVATED LOAD: Input loads activated by load multipliers.

Active pore pressures: Active pore pressures are the sumtotal of active steady state pore pressures and calculated excess pore pressures. Excess pore pressure can only result from deformations in 'undrained' soil layers. The steady state component consists of the active portion of the inputted initial and ultimate pore pressures.

$$p_{\text{active}} = \Sigma\text{-Mweight} \times p_{\text{initial}} + \Sigma\text{-Mchange} \times (p_{\text{ultimate}} - p_{\text{initial}}) + p_{\text{excess}} = 0 \quad (1)$$

In order to model a situation with three different groundwater tables, as indicated in Figure 1, situations A and B are entered during input in respectively the Initial and Ultimate pore pressure option. It is assumed that gravity is fully active ($\Sigma\text{-Mweight}=1.0$) and that the material behaviour is 'drained', hence no excess pore pressures can be generated ($p_{\text{excess}}=0$).

Activate pore pressures for situation A: Pore pressures from the initial situation are activated as soon as gravity is fully active. Use

the option Initial stresses or gravity loading to activate gravity. By default the load multiplier Σ -Mchange is zero, hence input of these values in formula (1) show that the initial pore pressures are fully active.

Activate pore pressures for situation B:

In a plastic calculation (ultimate level), the value for Σ -Mchange is raised from 0.0 to 1.0. As soon as Σ -Mchange is exactly 1.0, the inputted pore pressures from the ultimate situation are fully active (situation B). Pore pressures from the initial situation are no longer active. See also formula (1).

Activate pore pressures for situation C:

Change input:

Before situation C can be activated the input has to be changed. As Σ -Mchange=1, the initial pore pressures are not used, hence they can be redefined. Enter situation C, as initial

pore pressures.

Activate situation C:

In a plastic calculation (ultimate level), the value for Σ -Mchange is lowered from 1.0 to 0.0. As soon as Σ -Mchange has reached 0.0, the inputted pore pressures from the initial situation are fully active. As the inputted initial pore pressures have been changed to reflect situation C, the latter situation is fully active.

In case a fourth situation is to be modelled, the input of ultimate pore pressures can be changed (Σ -Mchange should be 0.0). Activate this situation by raising Σ -Mchange to 1.0. Obviously the above procedure can be repeated for any number of phreatic situations. A more detailed description of this procedure is given in the Groundwater manual (Version 6), page 3-5.

ACTIVITIES

30 SEPTEMBER - 2 OCTOBER 1996

EuroGeo 1, Geosynthetics Conference Workshop 2C 'Numerical Methodes' (demonstration and hands-on exercises), Maastricht, the Netherlands

14-15 OCTOBER 1996

3rd European Users meeting, Karlsruhe, Germany

25 OCTOBER 1996

Workshop Plaxis Users Association (NL), Delft, the Netherlands

20-24 JANUARY 1997

Course 'Computational Geomechanics' Noordwijkerhout, the Netherlands

JUNE-JULY 1997

Course for experienced Plaxis users, Noordwijkerhout, the Netherlands

OCTOBER 1997

Short course 'Computational Geomechanics', Kuala Lumpur, Malaysia

For more information on these activities, please contact:

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